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DISCRIMINANT AND FACTOR ANALYSIS OF GEOCHEMICAL DATA FROM GRANITOID ROCKS HOSTING THE MILLET BROOK URANIUM MINERALIZATION, SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA

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ABSTRACT

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The Millet Brook uranium deposit of Nova Scotia occurs as closely spaced en-echelon pods and lenses within a northeasterly trending fracture zone over more than 1 km within 370 Ma old biotite granodiorite, the least differentiated phase of the granitoid rocks of the South Mountain batholith. The main ore zone is found in a 240 m strike length, and total reserves for three zones have been estimated at about one million pounds of U_3O_8 at grades between 0.15 and 0.20 percent. The mineralization is thought to be related to magmatic fluids derived from younger, more differentiated leucomonzogranite found as dykes and a cupola underlying it. The mineralization is surrounded by alteration zones up to 30 m wide, and represented by four main types, viz. potassic, sodic, ferruginous and calcic, marked particularly by loss of silica and enrichment of carbonate, analogous to the episyenites associated with similar deposits of western Europe. An evaluation of the numerous chemical changes accompanying this alteration has been made for 33 elements in 128 samples using the statistical techniques of correlation, discriminant function, and R-mode factor analysis. These show that patterns indicated by petrographic studies can be confirmed with a high degree of statistical confidence, and that other more subtle element associations and patterns can be recognized which may have broader metallogenic significance and metallogenic application.

INTRODUCTION

Many vein-type uranium deposits are associated with peraluminous muscovite-bearing granitoid rocks, and occur in alteration zones marked by substantial loss of quartz and addition of carbonates and oxides (Rich et al., 1977). Such deposits are best known in France, where the alteration zones are termed "episyenite" because of the decrease in quartz content (Moreau and Ranchin, 1973), but they occur throughout the Hercynian granitoid terrains of Europe, and similar deposits have recently been discovered in Nova Scotia.

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Although such vein-type deposits have been interpreted as having a "paleosurface" origin related to downward-percolating groundwaters, i.e. the "per descensum" model (Barbier, 1969, 1974), recent studies have convincingly demonstrated an origin involving CO_2-rich hydrothermal fluids (e.g. Cuney, 1978; Leroy, 1978). Strong (1982) has recently described similar alteration of high-temperature origin, and emphasized the role of carbon dioxide in the hydrothermal fluid for transport and deposition of both U and Sn. The newly discovered Millet Brook deposit of Nova Scotia provides an opportunity for detailed study of the chemical changes which accompany CO_2-dominated alteration and uranium deposition. The large amount of data available for this deposit lends itself especially to study by multivariate statistical techniques.

GEOLOGICAL SETTING OF THE MILLET BROOK DEPOSIT

Uranium mineralization at Millet Brook, about 50 km west-northwest of Halifax, occurs in the South Mountain batholith, a post-tectonic peraluminous granodiorite—granite complex which outcrops over an area of more than 10,000 km^2 in southwestern Nova Scotia (Fig. 1).

The South Mountain batholith intrudes mainly deformed greywackes and pelites of the Cambro-Ordovician Meguma Group, but along its northwestern margin it cuts metasedimentary and metavolcanic rocks ranging in age from Ordovician to Lower Devonian (Emsian). Deformation and metamorphism of the country rocks is attributed to the Acadian orogeny, which in this region has been dated at 415 — 400 Ma (Reynolds et al., 1981). Stratigraphic controls bracket the time of intrusion, crystallization, uplift and erosion of the batholith between Emsian and Tournaisian times. Recent K/Ar and $^{40}Ar/^{39}Ar$ (Reynolds and Muecke, 1978; Reynolds et al., 1981) and Rb/Sr isochron studies (Clarke and Halliday, 1980) assign ages of 372 — 361 Ma to the various episodes of intrusion in the batholith.

Biotite granodiorite makes up most of the batholith, and it is intruded by a number of discrete smaller bodies of biotite—monzogranite (including porphyry), leucocratic monzogranite dykes, and irregular bodies of aplite and pegmatite. The major and many trace elements of this suite show continuous variation trends from the early to late-stage rocks. From these features, McKenzie and Clarke (1975) concluded that the batholith comprizes a 'cogenetic' suite with chemical variation controlled by fractional crystallization of mainly plagioclase and biotite.

Muecke and Clarke (1981), using rare-earth elements and Sr isotope data, and Chatterjee (1980) using other geochemical characteristics, recognized a 'para-intrusive' suite which appears to be the product of interaction of hydrothermal fluids with residual magma and the crystallized cogenetic suite. The para-intrusive suite is spatially and genetically associated with the various types of mineralization, and consists of two-mica leucogranites, argillized and sericitized granites, albitized granites, albitites, greisen, and

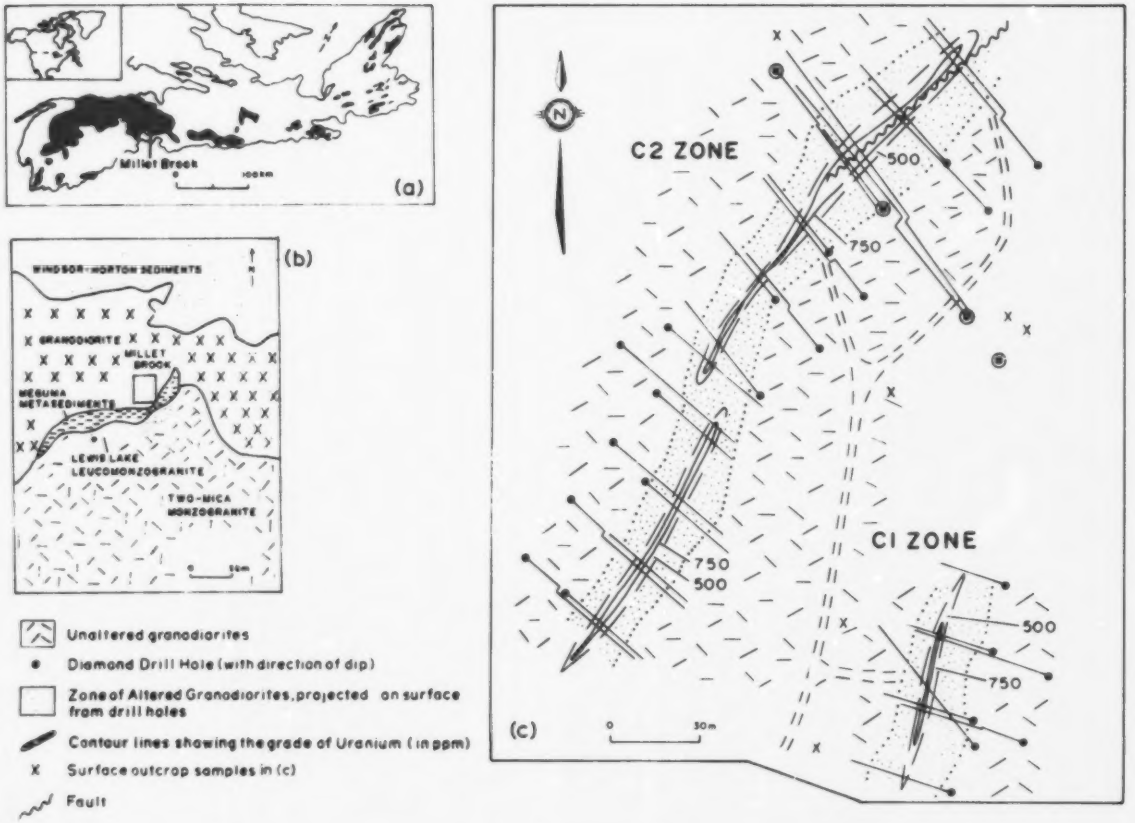

Fig. 1. Locality and geological setting of the Millet Brook uranium prospect (after Chatterjee et al., 1982), showing the mineralized zone and the location of drill cores from which the samples for the present study were taken.

various other hydrothermally altered granitoid rocks. The patterns of chemical variation of this suite are distinct and clearly diverge from those observed in the cogenetic suite.

At Millet Brook the para-intrusive suite is represented by the nearby Lewis Lake pluton, as well as an underlying cupola and late-stage dykes of leucomonzogranite. Chatterjee et al. (1982) have shown that the Lewis Lake pluton has lost approximately 70% of its original U content from the top 100 m, and suggest that this resulted from resurgent boiling and evolution of hydrothermal fluids which were responsible for the extensive fracturing, alteration and uranium depletion. They suggest a similar origin for the Millet Brook mineralization in the South Mountain granodiorite, i.e. resulting from fluids derived from and driven by heat from the underlying leucomonzogranite cupola.

The Millet Brook mineralization was discovered in 1977 by Aquitaine Company of Canada Ltd. (now Kidd Creek Mines Ltd.) by investigation of airborne radiometric anomalies (Chatterjee et al., 1982). In 1979, further mineralization was found by ground scintillometer prospecting at nearby Salter Lake, about 1.5 km west of the Millet Brook C1 and C2 zones (Fig. 1, left below). Diamond drilling has outlined a mineralized zone extending over a 240 m strike distance in a northeasterly direction, with total reserves estimated at about 1.0 million pounds of U_3O_8 with an average grade of 0.15—0.20% U_3O_8, at a cutt-off grade of 0.10% over a 2.0 m width. The Millet Brook uranium mineralization occurs in closely spaced en-echelon pods and lenses which are confined to northeast-trending shear and fracture zones in the 370-Ma biotite granodiorite, the dominant and the least differentiated rock type of the South Mountain batholith (Chatterjee and Muecke, 1982). The unaltered granodiorite is characterized by quartz, zoned plagioclase ($\sim An^{33}$), perthitic K-feldspar ($\sim Or^{90}Ab^{10}$), biotite (F/M = 2.04), muscovite, and accessory Mn-rich garnet, apatite, zircon, pyrite, pyrrhotite, ilmenite and rutile.

The altered granitoid rocks which are generally confined to within 30 m of the mineralized fractures include potassic, sodic, calcic, and ferruginous varieties of alteration (Chatterjee et al., 1982) which can be recognized as distinct chemical groups, as discussed below. The alteration minerals include K-feldspar, albite, biotite, muscovite, chlorite, and carbonate, the latter being dominant. In general, the altered rocks have a varied and complex mineralogy, and composition of the secondary minerals is dependent on the composition of the pre-existing primary magmatic minerals from which they were derived. For example, rapakivii mantling ($\sim An^{5}$) of earlier feldspar, development of phengites and chlorites from biotite (resulting in a strong positive correlation (r = 0.89) of Mg/[Mg+Fe(T)] ionic ratios between chlorites and phengites), and the development of secondary biotites which show systematic changes on approaching the mineralized zones, in the annite component from 0.654 to 0.597, octahedral Al from 0.68 to 0.87, and octahedral Ti from 0.40 to 0.60.

Ore minerals of the mineralized granodiorites are characterized by pitchblende, torbernite, autinite, and Pb-meta-autinite, together with minor amounts of chalcopyrite, bornite, covellite, chalcocite, proustite, galena, sphalerite, saleite, and wolframite. The associated gangue minerals are quartz, feldspars, micas, illite-smectite, andalusite, hematite, kaolinite, tourmaline, chlorite, calcite—ankerite, pyrite, Mn-oxides, and anatase.

GEOCHEMISTRY

One hundred and twenty-eight samples, for which both major and trace-element data are available (Chatterjee et al., 1982), were selected from the C1 and C2 zones as representative of the various types of granitoid rocks associated with the mineralized zones of the Millet Brook area. Samples were collected from the available diamond drill core, with one 10 cm-long sample being taken every five m along cores perpendicular to the C1 and C2 zones (Fig. 1, c). This covers a sequence passing symmetrically from the unaltered through altered to mineralized zones, and represents a vertical depth of more than 165 m. Each sample was split into three representatives for analysis, thin sectioning, and storage. The analytical data are available from the first author on request, and average compositions of the unaltered, altered, and mineralized groups are given in Table I.

Chatterjee and Muecke (1982) have shown that for most of the plutons in the South Mountain batholith the U content increases with increasing degree of differentiation, whereas Th and rare earth elements (REE) steadily decrease in abundance. The mean Th/U ratio changes from about 3 in the granodiorite to about 0.5 in the leucomonzogranite. This decrease in REE, Th, and Th/U with differentiation is accompanied by progressive enrichment in F, Be, Li, Rb, Cs, Ta, Sn, and U, and a depletion in Sr, Ba, Sc, Zr, and Hf. In the associated para-intrusive suite these element correlations tend to break down and particular elements may show more extreme enrichment (e.g. in U, Sn, Li) or depletion (e.g. in REE, Th), reflecting the changing chemical environment from magmatic to hydrothermal conditions.

The hydrothermal activity is further indicated by the pitchblende compositions (Fig. 2), which are significantly depleted in Th and enriched in V, features typical of hydrothermal uranium deposits. Figure 2 also shows that the Millet Brook pitchblendes have numerous chemical differences from those of meteoric uranium deposits.

The unaltered granodiorite of the Millet Brook area (Table I) is geochemically homogeneous and the major oxides and many trace elements are characterized by low standard deviations, exceptions being Ba (=155), Cu (=52), Rb (=22), Zn (=75), and Li (=14). The average concentrations of uranium (x=5.8 ppm) and thorium (x=10.9 ppm) are in agreement with the values given by Chatterjee and Muecke (1982) for the average granodiorite of the South Mountain batholith. In general there is an increase in variance from the unaltered through the altered to the mineralized granodiorite, and

this is especially striking for SiO_2, CaO, CO_2, Cu, Sr, Zn, and U (Table I). These patterns of chemical alteration can be further clarified by means of multivariate statistical techniques.

Multivariate statistical analysis deals with procedures for summarizing, representing, and analyzing multiple quantitative measurements obtained on a number of individual samples. In the present study, correlation analysis, stepwise discriminant analysis, and factor analysis were successively performed on the 31 chemical variables of the 128 granitoid samples, following

TABLE I

Average compositions of granodiorite from the Millet Brook area. Oxides in wt.%, trace elements in ppm

	Unaltered granodiorite		Altered granodiorite		Mineralized granodiorite	
	X ($n = 45$)	σ	X ($n = 67$)	σ	X ($n = 16$)	σ
SiO_2	68.31	1.28	70.63	1.82	66.54	6.91
TiO_2	0.76	0.13	0.71	0.05	0.61	0.04
Al_2O_3	14.80	0.72	13.72	0.80	13.77	2.30
Fe_2O_{3T}	4.69	0.42	4.41	0.73	4.51	0.37
FeO	3.72	0.40	3.37	0.44	2.68	0.38
MnO	0.07	0.01	0.07	0.01	0.09	0.08
MgO	1.23	0.22	1.23	0.24	1.12	0.11
CaO	1.73	0.40	1.33	0.50	3.16	4.65
K_2O	4.02	0.60	3.89	0.48	3.46	0.84
Na_2O	3.25	0.29	3.06	0.35	3.06	0.77
H_2O^+	1.02	0.25	1.13	0.33	1.60	0.45
H_2O^-	0.09	0.06	0.12	0.10	0.17	0.23
P_2O_5	0.22	0.08	0.19	0.03m	0.21	0.02
CO_2	0.12	0.08	0.08	0.04	1.43	2.91
Ba	622	155	573	120	518	132
Cu	29	52	60	124	419	537
F	518	95	540	100	433	100
Mo	2.1	0.77	2.1	0.84	3.4	0.66
Pb	28	12	29	12	47	23
Rb	168	22	164	15	140	20
Sn	4.4	0.6	4.6	0.8	4.6	1.26
Sr	139	20	122	20	121	60
Zn	141	75	138	79	327	271
U	6	3	16	20	781	736
B	17	14	30	50	45	21
Be	3	1	2.7	0.92	2.2	1.2
Bi	0.1	0.1	0.06	0.01	0.1	0.01
Li	92	14	90	18	90	13
Co	7	2	7	1.8	18	13
Ni	12	3.5	11	2.6	16	1.4
Th	10.9	1.8	10.6	1.0	8.3	0.8

logarithmic transformation of the data, using the routine programs available in the SPSS system (Nie et al., 1975). The detailed calculations and results are available on request, and only the more significant observations are presented here.

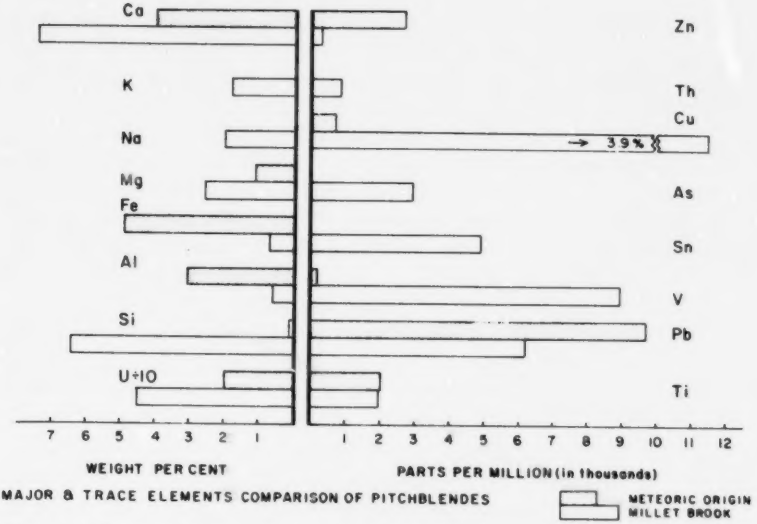

Fig. 2. Chemical characteristics of pitchblende from the Millet Brook uranium deposit, compared to those for typical meteoric deposits.

Correlation coefficients were calculated for the total population, and independently on sub-groups of the unaltered granodiorites, the altered granodiorites, and the mineralized granodiorites, in order to illustrate the changing patterns of element association with progressive stages of alteration. These correlation matrices show the difficulty of assessing strong inter-element correlations in terms of meaningful geological parameters. In the total population, for example, most elements are correlated, either positively or negatively, with better than 99.9% confidence, despite the fact that a number of geologically distinct sub-groups are included.

The unaltered granodiorites, on the other hand, show a 99% confidence level of correlation between only a few elements, mainly those of biotite (TiO_2, MnO, FeO, Fe_2O_3, F). SiO_2 is negatively correlated against the components of feldspar (K_2O, Na_2O, Al_2O_3, Ba, Sr), and the trace elements Li, Zn, Be, B, Cu, Pb, and U all show strong positive correlations, resulting from their concentrations in the group of accessory minerals, although not necessarily in the same mineral.

The altered granodiorites show strong correlations of better than 99.9% confidence between many more elements than do the unaltered granodiorites. Along with the mutual correlations between the "biotite components"

seen in the latter, the altered granodiorites also show strong correlations between these elements and a number of trace elements such as Sn, Zn, Li, Co, Ni, and Th. Uranium, the main element of interest in this study, changes with alteration from a correlation with only Zn and Pb to one with CaO, Sr, Be, and Li, an incongruous assemblage of no obvious genetic significance.

The correlation patterns change even more in the mineralized granodiorites. For example U now shows strong positive correlations with Sn, Cu, CO_2, CaO, MnO, and Co, and negative correlations with Li, P_2O_5, Na_2O, MgO, FeO, Al_2O_3, and TiO_2, compared to only five elements in the unaltered granodiorites. These changing patterns indicate that with increasing intensity of secondary processes (e.g. oxidation, alteration, mineralization), more elements become affected along with the readily mobile uranium, compared with the purely magmatic processes of the unaltered granodiorites where uranium behaviour would be significantly different from that of most other elements. Because it can be shown petrographically that the altered granodiorites do in fact contain a number of sub-groups, i.e. silicic, potassic, etc., as described above, it is important to investigate whether these sub-groups can be chemically distinguished and hence refine the correlation analysis. This was done by means of discriminant function analysis.

Discriminant analysis treats the problem of differentiating between two or more classes of objects, and mathematical details are given by numerous textbooks (e.g. Anderson, 1958; Koch and Link, 1971). The statistical problem consists of developing a rule or "discriminant function" based on measurements obtained for each sample in order to develop a linear combination, L, of the variables (in our case SiO_2, TiO_2, ...U, Th). It is clear that if L is going to discriminate between the two populations (e.g., unaltered granodiorite vs altered granodiorite), differences in the value of L between the two groups should be much greater than the variation within each group. In step-wise discriminant analysis, one variable is included to calculate a discriminant function in cumulative steps, this variable being the one that results in the most significant L value after adjusting for variables already included in the model. When two groups are classified, only one discriminant function is needed or can be calculated, with three groups two functions can be calculated, with four groups three functions, and so on for multiple group discrimination.

In this study a single discriminant function was calculated to distinguish between the unaltered and the altered granodiorites, as follows:

$$L = (0.365)SiO_2 + (0.554)TiO_2 - (0.309)Fe_2O_3 + (0.549)MnO - (1.662)CaO - (0.510)Cu + (0.264)F - (0.991)Rb + (0.625)Sn - (1.151)Bi + (0.952)U + (0.489)B - (0.570)Be - (0.408)Ni.$$

The values of this function are plotted for the analysed samples as a histogram in Fig. 3, where it can be seen that, while there is no overlap between the two groups, one of the main mathematical criteria for reliable discrimination is not satisfied, namely that within-group variance (within the altered

granodiorites) is greater than that between the two groups. It does show, however, that the altered granodiorites fall into four separate groups, suggesting that the four alteration types noted above (Chatterjee et al., 1982), i.e. potassic, sodic, calcic and ferruginous, might be successfully recognized by step-wise multiple discrimination.

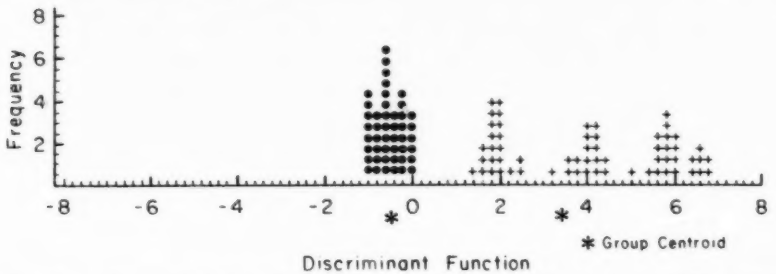

Fig. 3. Frequency distribution of values of the discriminant function scores for 128 samples separating the unaltered (dots) from the altered (crosses) granodiorites of the Millet Brook area. Note the large variance and the presence of subgroups within the altered granodiorites.

The four alteration types and the unaltered granodiorites were thus used to calculate four discriminant functions. The average values (centroids) of the first and second functions ($L1$, $L2$) for each group are plotted in Fig. 4. It can be seen from Fig. 4 that the unaltered granodiorites form a very restricted cluster, whereas the altered granodiorites are represented by four subgroups. These sub-groups are the result of the different alteration processes which result in silicification, albitization, etc. There is overlap of only two samples which may have been petrographically misclassified. It should be noted that this consistency of classification cannot be attained by the straightforward plotting of individual element concentrations. In order to confirm that such groupings were valid, i.e. that they could be recognized independently of petrographic classifications, we turned to factor analysis.

Factor analysis explains the relationships among several correlated variables that are difficult to interpret in terms of a few conceptually meaningful relatively independent factors. For mathematical definitions and classifications of factor analysis we recommend Kim (1975) and Klovan (1975).

In simple terms a factor, F, is a weighted linear combination of the original variables (in the present case 31) into one or more composite variables which summarize the essential information contained in all of them. Thus, factor analysis is helpful in the task of reducing the number of measurements needed to describe a phenomenon, i.e. to recognize patterns, but the interpretation of such patterns is largely non-statistical.

R-mode factor analysis, using the principal components method (Wilks, 1962), followed by varimax rotation (orthogonal) of the factor scores, was used to decrease the number of variables involved in the discriminant func-

tion and to define the chemical variability of the granitoid rocks.

As shown from the cumulative variance curves in Fig. 5, the first five factors calculated for the unaltered granodiorites account for 78% of the variance, and the first three account for 58% of it. The first four factors are plotted in Fig. 6, showing that most elements have relatively low factor loadings grouped into a small number of clusters. The cluster of Fe_2O_3, FeO, MgO, and TiO_2, as also suggested by the correlation coefficients discussed above, can be termed a "biotite cluster". At the other extreme, the cluster of K_2O, Na_2O, SiO_2, Al_2O_3, Ba and Sr can be explained in terms of a "feldspar plus quartz cluster". The quartz and feldspar produce separate clusters with factor 3. Between these extremes, with consistently low factor loadings, P_2O_5 and the trace elements Li, B, Cu, Sn, Be, Ni, Co, F, and Mo are readily assigned to an "accessory mineral cluster". The high factor-2 loadings for Pb, Zn and U might reflect sulphides and uraninite respectively, but we see no particular reason why they should occur together. Plagioclase and fluorite may explain why CaO should be separated with a large negative loading for factor 2, as well as the CaO—F clustering with factor 4.

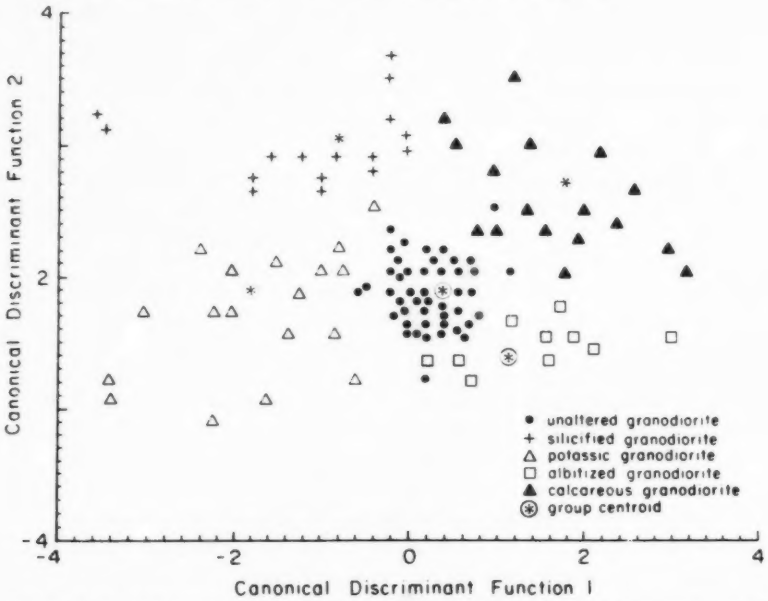

Fig. 4. A plot of the stepwise discriminant functions 1 and 2 determined for the five subgroups of samples from the Millet Brook area. Note the distinct differences between the centroids (averages) of the different subgroups.

The variability in altered granodiorites is 77% accounted for by the first four factors, and 51% accounted for by factors 1 and 2 (Fig. 5). Factors 1 and 2 (Fig. 7) show different clusters than in the unaltered granodiorites.

For example, TiO_2, FeO and Fe_2O_3 (an oxide cluster) are separated from MgO and H_2O+ (a chlorite cluster). Likewise, K_2O and Na_2O are separated by the processes of sericitization and albitization, with Al_2O_3 "shared" between the two. Except for SiO_2, the broad cluster with low scores between Ni and Th includes most of the elements of the "accessory cluster" in the unaltered granodiorite. The clustering of Sn and Na_2O with all factors is reminiscent of the common accompaniment of Sn mineralization with albitization, although there is no indication of significant Sn enrichment in these rocks (Table I).

Factor analysis of the mineralized granodiorites (Fig. 8) produces a much stronger clustering and higher factor loadings than either the altered or

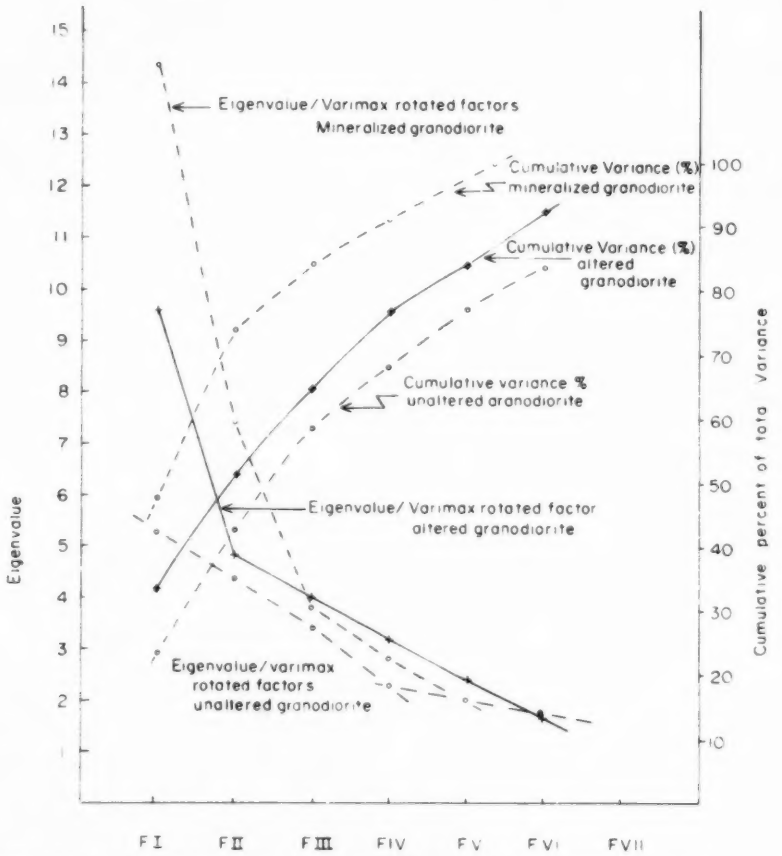

Fig. 5. A plot of the cumulative variance (percent) and the eigenvalue/varimax rotated factors for the unaltered, altered, and mineralized granitoid rocks of the Millet Brook area.

Fig. 6. Plots of factors 1, 2, 3, and 4 for elements determined in the unaltered granodiorites of the Millet Brook area.

Fig. 7. Plots of factors 1, 2, 3, and 4 for elements determined in the altered granodiorites of the Millet Brook area.

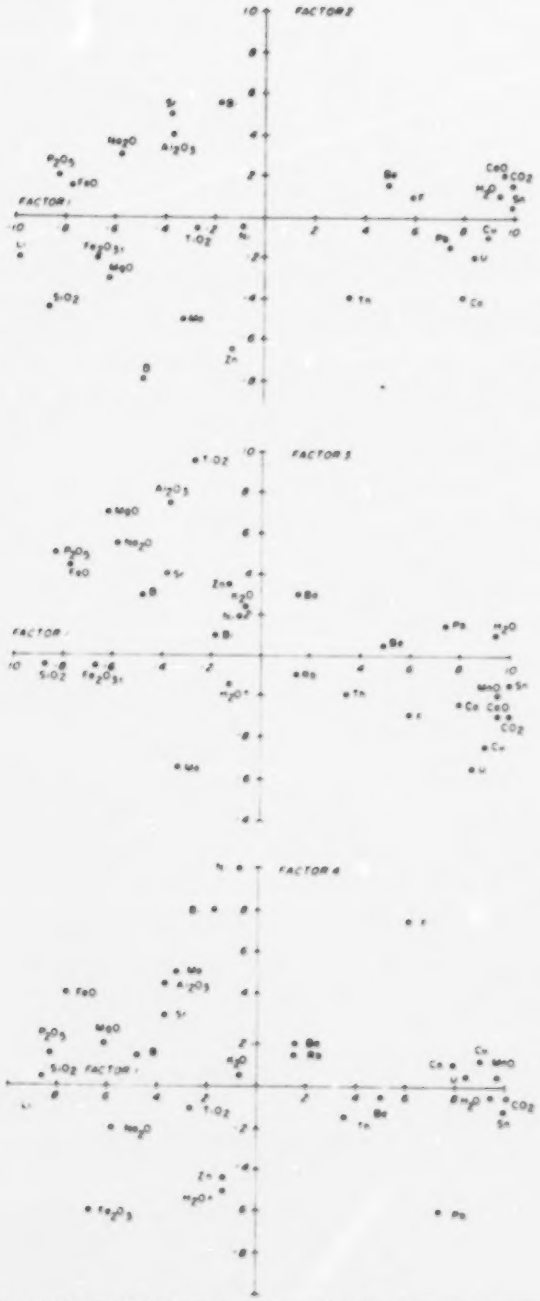

Fig. 8. Plots of factors 1, 2, 3, and 4 for elements determined in the mineralized granodiorites of the Millet Brook area.

unaltered granodiorites, with the first four factors accounting for more than 93% of the total variance, and factor 1 alone accounting for 47.6% (Fig. 5). The most striking feature of Fig. 8 is the coherence between all four factors of CaO, CO_2, H_2O, MnO, Sn, Cu, Co, and U, reflecting the association of the uranium mineralization with strong carbonate and some sulphide alteration. Their extreme separation from SiO_2 and other silicate-forming elements likewise reflects the loss of quartz ("episyenitization") involved in this alteration and mineralization.

SUMMARY AND DISCUSSION

The Devonian–Carboniferous post-tectonic South Mountain batholith of Nova Scotia is dominated by peraluminous granodiorite, intruded by a number of smaller stocks of more differentiated monzogranite to leucogranite. The uranium mineralization is found in alteration zones within the least differentiated biotite granodiorite, but is genetically associated with the later intrusions. The processes of alteration and mineralization resulted in numerous chemical effects, and the associations of elements and their patterns of variation are sensitive indicators of these processes and of the presence of mineralization. The successful recognition and identification of such features is one of the prime aims of geochemical studies, and this study was undertaken to evaluate the usefulness of multivariate statistical techniques in achieving these aims, in particular by stepwise multiple discriminant function analysis and R-mode factor analysis.

In the R-mode factor analysis, a principal components analysis was carried out on the 31 × 31 R-matrix with unity in the diagonals. Eigenvalues of the largest factors are plotted in Fig. 5, and the resulting curves can be seen to show significant changes in magnitude of the eigenvalues at breaks in their slopes. The different sectors of these curves can be related to the separate geological/geochemical processes responsible for variation of the factors in that sector. For example, the curve for unaltered granodiorite shows one break in slope at factor 4, suggesting that a single process controlled the factors 1 to 4, and that a separate process controlled the factors 4 to 6.

In the case of the mineralized granodiorites (Fig. 5), there are two breaks in slope, i.e. three sectors which can be related to three different processes. The sector between factors 1 and 2 reflects gangue mineralization (especially carbonate), that between factors 2 and 3 the main ore mineralization, and that between 3 and 6 the less significant accessory mineralization. The two sectors of the curve for the altered granodiorites can be interpreted as resulting from the two main types of alteration, viz. one carbonate-poor between factors 1 and 2, and one carbonate-rich between factors 2 and 6.

As for the important carbonate-dominated (episyenite) alteration, the elements Sn, Cu, U, Pb, Co, Ca, and Mn, and to a lesser extent F, Be, and Th were concentrated with the CO_2 and constitute a distinct geochemical

signature which should be useful in the search for other uranium mineralization of the Millet Brook type. It is probable that these elements were all transported in the hydrothermal solutions as carbonate complexes, and their deposition resulted from CO_2 exsolution from this fluid and its reaction with the host rocks, more or less as suggested for the similar uranium deposits of the French Central Massif by Cuney (1978) and Leroy (1978).

In other words, it has been demonstrated that multivariate statistical techniques can successfully link the numerical classification of granitoid rocks to mineralogical models based on petrographic classification of alteration assemblages. With some statistical confidence the multivariate techniques reveal a range of important element associations and patterns which can be associated with the different alteration and mineralization effects, and which may prove to have broader metallogenic and exploration significance.

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